PB84-215516

Microbiological Risks Associated with Changes in Drinking Water Disinfection Practices

(U.S.) Health Effects Research Lab.
Cincinnati, OH

Jul 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-215516

EPA-600/D-84-184
July 1984

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/D-84-184		PB84 215516

4. TITLE AND SUBTITLE	5. REPORT DATE
Microbiological Risks Associated With Changes in Drinking Water Disinfection Practices	July 1984
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Elmer W. Akin[1] and John C. Hoff[2]	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
1 TMD, HERL and 2 DWRD, MERL U.S. Environmental Protection Agency 26 West St. Clair Street Cincinnati, OH 45268	ABMC1A
	11. CONTRACT/GRANT NO.
	in-house
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Health Effects Research Laboratory U.S. Environmental Protection Agency, ORD Research Triangle Park, North Carolina 27711	14. SPONSORING AGENCY CODE EPA-600/11

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report briefly reviews the development of chlorination practice in the United States as more resistant waterborne pathogens were identified. The occurrence of waterborne outbreaks and the possibility of sporadic cases of waterborne infections are discussed as well as the use of alternative disinfectants.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
	Unclassified	28
Release to Public	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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INTRODUCTION

Since it's first application in Jersey City in 1908, the chlorination of drinking water to control microbiological contamination has become common practice in the United States. Although all community water supplies in this country are not disinfected with chlorine or any other agent or process, it is a widely held expert opinion that they should be disinfected to reduce the risk of waterborne infectious diseases. In fact, the AWWA disinfection committee has stated that all public water supplies must be disinfected.[1] EPA's Office of Drinking Water is now considering proposing a legal requirement for the application of this water treatment process.

Disinfection of water has been practically synonymous with chlorination for the 76 years it has been practiced in this country. Even with renewed interest in alternative disinfectants because of the chlorinated-organics health issue, there is strong economic and technical pressure to avoid the displacement of chlorine as the primary disinfectant in resolving this health concern. For this reason and the fact that most of the microbiological disinfection data have been obtained with chlorine, this report will focus on chlorination.

The decision to apply a "poison" or at best a "forced medication" to contaminated water to make it potable was not supported by all in those early years. As chlorination became more widely used for water treatment, public opinion often considered bad-tasting water synonymous with chlorinated water. Therefore, good public health practice was considered to be the addition of the absolute minimum amount of

chlorine that would kill indicator bacteria. This resulted in a common practice of adding about 0.25 ppm of total residual chlorine which typically yielded less than 0.1 ppm O-Tolidine-detectable residual after a 15-minute contact time.[2]

The public health significance of the chlorination of drinking water was demonstrated most clearly with the precipitious drop in typhoid fever deaths in the first third of this century. At the turn of the century, around 25,000 deaths and untold number of cases of typhoid fever occurred annually in the U.S. Waterborne transmission of the bacterium was believed to be responsible for perhaps 40% of the typhoid fever cases. By 1935, a 10-fold drop in typhoid fever deaths had occurred and improved water sanitation was given much of the credit. It was fortunate indeed that the chlorine level that was fairly acceptable from a taste and odor standpoint and reduced the Bacillus (now Escherichia) coli fecal indicator was also effective against Salmonella typhosa, the causative agent of typhoid fever.

Of course S. typhosa was not the only bacterial pathogen in sewage-contaminated drinking water that was a major public health hazard. An observation was made in 1903 that when a community's water supply is changed from a "poor" one to an "excellent" one, every person saved from a typhoid fever death was accompanied by three others saved from causes not obviously related to water contamination.[2] Therefore, the typhoid fever death rate became somewhat of a gauge for the sanitary condition of a community.

By mid-century the chemistry of water chlorination was more

clearly understood. Also, the existence of a large number of fecally-shed viruses had been detected through the application of cell culture isolation procedures. The studies on virus inactivation by chlorine species that soon followed these developments showed enteric viruses to be significantly more resistant to chlorine than bacterial indicators and enteric pathogens. These observations led to considerable concern over the drinking water transmission of viruses and the need for a more rigorous disinfection practice.

At about the same time, disinfection studies with the agent of amoebic dysentery, E. histolytica, revealed that the cysts of this waterborne pathogen were highly resistant to chlorine. Since the cysts were large enough to be removed by filtration, this method of control was considered to be the more practical approach.

This in turn led to the recommended chlorination practice, based on virus inactivation data, of treating with 0.4 to 1.0 mg/L of free residual chlorine for at least a 30-minute contact time.[3,4] However, in common practice, prechlorination was incorporated into most conventional treatment schemes that extended the chlorine contact time to 2-4 hours, usually at significantly elevated chlorine levels.

Whereas control of waterborne virus transmission had been viewed as the most significant problem facing disinfection in the '70s, control of waterborne giardiasis became the problem of the '80s. Since its first recognition as an important waterborne pathogen in 1974, Giardia has become the most frequently identified etiological agent of waterborne outbreaks in the U.S. Like E. histolytica, the

environmentally-stable cyst form of this parasite is also more resistant to chlorine inactivation than enteric bacteria and viruses.

COMPARATIVE MICROBIAL INACTIVATION

Efforts have been made to provide guidance on disinfection practice using linear rate-reduction data. Different types of enteric microorganisms were used in studies with different chlorine species. The products of the chlorine concentration (C) and contact time (t) for a given level of microbial inactivation, e.g., 99%, were obtained. Factors such as chlorine-demand, pH and temperature that were known to affect the reaction were stabilized. The product of C times t (C•t) then can be considered as a constant that reflects the relative disinfection sensitivity of each organism tested. The results of studies with some microorganisms are shown in Table I.

Full conventional treatment (prechlorination, flocculation, sedimentation, rapid filtration and post-disinfection), as it had evolved prior to the chlorinated-organics health concern, was believed to be completely adequate for producing drinking water safe from the spread of infectious diseases. This empirical knowledge was accepted in light of the fact that a large percent of the U.S. population was consuming treated water derived from sewage-polluted surface water sources. There is no clinical or epidemiological evidence to refute this claim when water is fully treated to meet the coliform and turbidity standards. However, incomplete treatment or deficiencies in unit processes as well as subsequent recontamination of treated water in distribution systems has resulted in documented episodes of

illness.

WATERBORNE OUTBREAKS

The formal collection and reporting of waterborne disease outbreak data has been ongoing in this country since 1920. Although reporting seems to have improved over the years, there is no claim that the data base is complete even for recent years. Investigation and reporting of infectious disease outbreaks is primarily a function of state and local health authorities and is strongly dependent upon interest, funding and the availability of properly skilled personnel. Nonetheless, these data provide considerable insight into the factors important in waterborne disease occurrence subsequent to the availability of enlightened water treatment technology.

The annual number of reported waterborne infectious disease outbreaks show an upward trend since 1966 to a modern-day high in 1980 of 43 with 17,710 cases of illness.[12,13] Lippy and Waltrip[12] have reviewed the data on 623 outbreaks that were reported for the 35-year period 1946-80. These outbreaks generally occurred in small surface water and ground water systems where full conventional treatment was not applied. In fact, a majority of the outbreaks occurred in systems that failed to apply or maintain any treatment (Table II). One may conclude from these data that the risk of waterborne infectious disease is increased in the absence of full conventional treatment. The data also show the health significance of recontaminated water in the distribution system. Of considerable importance in understanding and controlling waterborne illness is the fact that the causative

agent was not identified in over 50% of the outbreaks.

It is of interest to note some general features of water treatment plant facilities and operations relative to the occurrence of waterborne outbreaks. Fuhs[11] pointed out a basic consideration regarding the nature of source waters and the potential for waterborne transmission of disease. He distinguished between source waters receiving consistent pollution from large populations such as the Mississippi and lower Hudson rivers and source waters from smaller streams or impoundments in watershed areas virtually devoid of human populations. In the first case, pathogens are constantly present in the source water and any major deficiency in water treatment would likely result in a detectable outbreak of waterborne disease. In the second case, pathogens will be present only intermittently, and operational deficiencies will result in waterborne outbreaks only when a particular set of circumstances occur coincidentally with the defective treatment. In this situation, water-treatment personnel may become lax in operational matters because they observe that whether or not the water is treated apparently makes no difference. This circumstance, coupled with the fact that systems with relatively uncontaminated source waters are often small communities with limited facilities and less well-trained operators is likely a major factor in the predominance of waterborne outbreaks in these types of supplies.

RECENT CONCERNS REGARDING ESTABLISHED PRACTICE

In practice, it has been accepted that full conventional treatment is not required for all water supplies to protect the public

health. Some drinking water sources, particularly groundwaters, are thought to be free of pathogenic microorganisms and require no treatment. At best, marginal disinfection may be applied to comply with regulations or satisfy a view that chance contamination of the source water would be controlled. The outbreak record indicates that such treatment can be inadequate.

If water treatment is implemented for a given water supply, disinfection invariably will be included as the only or the final step. This practice is consistent with the widely held view, with considerable research support, that disinfection is the true barrier to waterborne disease transmission and that prior treatment steps only enhance the capability for effective disinfection. If sanitary surveys do not reveal a source of fecal contamination and the source water is relatively clear, disinfection, perhaps marginal, has been viewed as the only logical treatment needed. Many supplies have operated thusly for decades without the known occurrence of waterborne disease.

Of the many waterborne outbreaks that have occurred in the past few years, two stand out that especially shake confidence in the ability to predict water health risks and in the capability of limited treatment to protect against major episodes of waterborne disease. In June 1980, an outbreak of gastroenteritis (about 8,000 cases) followed by an outbreak of about 36 cases of hepatitis A occurred in a small Texas community that utilized chlorinated deep groundwater as its drinking water.[14] The yet unexplained contamination of wells in

the central-city area is believed to be the source of the unidentified etiological agents. Chlorination of the water supply was believed to be adequate with an assumed 30-minute contact time to protect against unexpected contamination of the source water. After performing an engineering evaluation of the water system, Lippy[15] found that the contact time was considerably less and that chlorine was not applied proportional to water volume delivered. Treatment that had been considered sufficient for decades was determined after the occurrence of a major outbreak to be inadequate.

Similar confidence for many years has been placed in disinfection-only treatment of several impounded surface water sources in eastern Pennsylvania. In recent months, at least 400 confirmed cases of giardiasis were believed to have been caused by contaminated drinking water from two chlorinated supplies. Across the state, a filtered and chlorinated river supply produced by an outdated plant was believed to be responsible for an additional 300 cases. During a period in late December/early January an abnormally high demand for water in this community had left insufficient volume to backwash the filters. For six days during this period, turbidity rose from a typical value of <1.0 turbidity units to >4.0 units. Chlorine values during the four weeks immediately prior to the outbreak remained practically unchanged at an average of 1.2 mg/L and 1.5 mg/L free and total residuals, respectively. Coliform tests on 10 ml volumes of the finished water samples during and immediately prior to the outbreak did not exceed two positive tubes of the 35 tubes inocu-

lated each week. These data indicate a slight deterioration in water quality occurred but typically would not be interpreted to indicate a health hazard. Drinking water samples collected from the three supplies subsequent to the outbreaks have been anlayzed for Giardia cysts. Investigators from EPA analyzed 12 samples and detected cysts in 5 of these. During this period, over 350,000 people on treated water supplies in Pennsylvania were advised by health authorities to boil their water to assure protection from waterborne giardiasis.

OCCURRENCE OF VIRUS IN DRINKING WATER

In addition to the outbreak data, the occurrence of infectious viruses in treated water has been demonstrated on a number of occasions in the absence of known waterborne disease (Table III). The most notable of these virus isolations have been those from studies in Canada and Mexico. Payment[18] found 11/155 (7%) 1000-L samples of fully-treated drinking water from the Montreal area to be positive for infectious viruses. Viruses were recovered from 121/153 (79%) of the 100-L samples of the surface source water. In a more recent study of a Mexico community supply, Gerba and Keswick[19] found that a significant percentage of finished water samples that were positive for enteric viruses had acceptable free chlorine residuals and met the U.S. standard for coliforms and turidity.

Viruses have been detected in treated drinking waters using improved recovery methods in sample volumes of a few hundred liters. These findings are at odds with prediction models based on typical virus levels found in raw source waters and reductions achieved with

in vitro treatment systems using seeded viruses. Sproul[20] predicted that a water treatment scheme that incorporates coagulation, filtration and chlorination (0.5 mg/L free residual for 30-minute contact) could reduce the virus level by seven logs. Therefore, source water having a high contamination level of about one viral unit per liter would be treated to contain one viral unit per 10 million liters in the finished product. The finding of viruses in much smaller volumes of treated water than the model predicted suggests that naturally-occurring viruses may not be removed/inactivated in actual plant operation as effectively as are laboratory-grown seeded virus. Indeed this possibility is supported by studies showing reduced disinfectant inactivation of clumped viruses and viruses adsorbed to cell debris.[21,22]

Even considering the unexplained positive virus findings in fully-treated drinking water and the occurrence of waterborne disease outbreaks associated with chlorinated supplies, confidence in chlorination as an effective disinfection process remains high. No microbial pathogens are known to be innately resistant to chlorine in an absolute sense. Therefore, a rigorous chlorination procedure that provided adequate contact time, continuous application and appropriate residuals during treatment and distribution to a clarified water was believed to be adequate to produce microbiologically-safe drinking water.

ALTERNATIVE DISINFECTANTS AND PROCEDURES

The previously assumed safety of relatively high concentrations

of chlorine in drinking water to control microorganisms has been tempered by the more recent concern over health effects of chlorinated organic chemicals produced during the chlorination process when free chlorine residuals occur. This concern and the resultant regulatory limits on trihalomethane (THM) levels in drinking water[23] has stimulated considerable interest in alternative disinfection processes. In a recent survey of 24 community water supplies that had modified their treatment process in order to lower THM levels, nine had changed the point of chlorination, ten had changed to chloramination and one had switched to chlorine dioxide.[24]

Changes in chlorine application in the treatment chain from a presedimentation to a post-sedimentation point reduces the level of THM-precursor chemicals available for chlorine reactivity. Chlorine application rates often are reduced in this process since chlorine-demand materials are removed. This relatively simple change has been successful in lowering THM's to an acceptable level. However, the chlorine contact time for microbial destruction prior to distribution of the water may be significantly reduced. One comprehensive study has reported on the occurrence of enteric viruses in a water treatment plant that modified the point of chlorination.[25] The supply was found to have high virus levels in the surface source and high THM concentrations (average of five samples was 338 µg/L) in the finished water. Treatment prior to the study consisted of adding 7 to 10 mg/L of chlorine just prior to the rapid mixing phase of the sedimentation process (prechlorination). During the study, chlorination was moved

to a point just after the sand filtration step. Water samples were collected three times per month for 13 months and analyzed for THM levels, viruses and coliform indicators.

Key results of this study are summarized in Table IV. The change in chlorination practice did not appear to compromise the microbiological quality of the finished water during the study period as indicated by negative virus and coliform findings. It should be noted, however, that even under the modified chlorination procedure, chlorine residual and contact time at this plant far exceeded the recommended values. The filtered water, having a pH below 8.0 and turbidity below 1.0 NTU, had been dosed with 5-7 mg/L of chlorine and stored in a reservoir for at least 16 hours prior to sample collection. It is of interest to note that in this system, an acceptable THM level, i.e., $\leq$100 µ/ml, was not achieved with the treatment modification.

The addition of ammonia prior to or just after chlorine addition in a ratio of 3:1 has been used to produce combined chlorine residuals that do not react further to produce THM's. This procedure has been in use for many years to prevent sporadic taste and odor problems and also, because of the stability of the combined form, to insure chloramine residual throughout a distribution system. Chloramination has been discouraged by many in public health because a number of studies have shown the combined chlorine residuals to be considerably less microbicidal than the free residuals for the same contact period.[26] However, in practice chloramination has produced finished water that meets the microbiological standards and no known waterborne outbreaks

have been attributed to an inadequacy of this disinfectant.

In addition to the one water supply in the survey that converted from chlorine, about 85 other treatment plants in the U.S. use chlorine dioxide for disinfection.[27] Chlorine dioxide is a stronger oxidant than chlorine and has been shown to be an effective microbicide. Although only a limited number of studies have been conducted with waterborne pathogens, it is likely to be superior to chlorine as a disinfectant, especially in alkaline waters.

Although ozone disinfection was not selected by any of the plants in the survey, it is a viable alternative to chlorine that does not yield THM's. About 52 supplies in the U.S. are now or soon will be using ozone for water disinfection.[27] It can be as effective as chlorine in primary disinfection of drinking water but has the disadvantage when used alone of not providing a residual to protect the distribution system against subsequent contamination. Other alternative disinfectants to those mentioned above do not appear practical at the present time due to cost, technical or other disadvantages.

RISK OF WATERBORNE DISEASE

The basic expectation concerning drinking water quality in this country is that no infectious agents should be present. Disinfection has been relied upon to achieve this expectation. Animal feeding studies conducted in the 1950's and 1960's[28,29] had indicated that chlorine posed no health hazard at concentrations up to 200 mg/L of drinking water. Therefore, high levels were freely applied to drinking water derived from contaminated sources. Application rates of 10

mg/L as a prechlorination step have not been uncommon. It is doubtful that very many of the supplies derived from river and stream sources limited their chlorination practice to the recommended 0.5 to 1.0 mg/L of free residual chlorine for a 30-minute contact period. It appears that the full-conventional treatment process that evolved for sewage-contaminated source waters has been effective. No outbreaks have been attributed to an inadequacy of this process. However, the occurrence of sporadic cases of infectious disease, not obviously associated with water, has been suggested.[30]

Gastroenteritis is a common malady in the U.S. population. Studies of persons of ages <1 through 50 years indicate an average incidence of 1.2 episodes of enteric illness each year.[31] A number of potentially-waterborne enteric microorganisms can cause gastroenteritis, and indeed, this disease is the one most commonly associated with waterborne outbreaks. The significance, if any, of the water route in the transmission of this disease in other than outbreak occurrences has not been determined. However, the isolation of enteric virus from large-volume samples of fully-treated water meeting current standards is cause for concern. Human feeding studies have determined that many of the enteric pathogens have relatively low infective dose numbers for healthy volunteers (Table V). More susceptible segments of the population would likely be infected with significantly lower numbers, perhaps at levels undetectable in water with current methodology.

Even though no firm evidence exists for the occurrence of sporad-

ic waterborne infections, reductions in disinfection capability is of concern. The effectiveness of 0.5 mg/L of chlorine for only 30 minutes contact before water is distributed to the consumer has not been thoroughly evaluated under worst case conditions. Reductions in disinfection potency resulting from a switch to combined chlorine as the primary disinfectant may allow low level penetration of the more resistant pathogens. The switch to potent oxidizing agents such as chlorine dioxide and ozone may also increase the likelihood of pathogen penetration. This could occur from failure to consistently maintain a sufficient disinfection level in the water because of personnel inexperience with the process or technological failure of unproven delivery systems. At this time the existence of increased risk of infectious disease from the use of alternative disinfection agents and practices are unproven. However, very little study has addressed this question. Increased surveillance for deterioration in microbiological water quality and the occurrence of waterborne disease in the consuming population is certainly warranted.

ACKNOWLEDGMENTS

The authors thank Jon Capacasa, John Stoecker, John Ashton and Judith Sauch for information concerning the Pennsylvania Giardia outbreaks and Dixie White for clerical assistance in preparing the manuscript.

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Table I. Comparative Inactivation of Selected Enteric Organisms to Different Species of Chlorine

	Water		Chlorine				
Microoganism	pH	Temp. (°C)	Species	Conc. (mg/L)	Time[a] (min)	C·t[b]	Reference
E. coli	6.0	5	HOCl	0.1	0.4	.04	5
E. coli	10.0	5	OCl^-	1.0	0.9	0.9	5
E. coli	9.0	5	NH_2Cl	1.0	175	175	6
E. coli	9.0	15	NH_2Cl	1.0	64	64	6
Poliovirus 1	6.0	5	HOCl	0.5	2.0	1.0	7
Poliovirus 1	10.0	5	OCl^-	0.5	21	10.5	7
Poliovirus 1	9.0	15	NH_2Cl	10.0	90	900	6
E. histolytica	6.0	5	HOCl	5.0	18	90	8
G. lamblia (cysts)	6.0	5	HOCl	2.0	40	80	9
G. lamblia (cysts)	7.5	3	NH_2Cl	2.4	220	528	10

a = Contact time to yield 99% inactivation.
b = Product of Concentration (C) times contact time (t).

Table II. Deficiencies Associated with Waterborne Disease Outbreaks in Public Water System for the Period 1946-1980[12]

Deficiency	Percentage of Outbreaks
Contaminated Untreated Groundwater	35.3
Inadequate or Interrupted Treatment	27.2
Distribution Network Problems	20.8
Contaminated Untreated Surface Water	8.3
Miscellaneous	8.3

Table III. Reported Isolations of Human Viruses from Treated Drinking Water During the Past Decade[16,17]

Location	Date	Water Treatment	Samples No. Pos./No. Taken	Virus Type(s) Isolated
Canada	1983	Complete[a]	11/155	Polio, Coxsackie
France	1982	NR[b]	2/219	Polio, Coxsackie
Texas	1980	Disinfection	3/6	Coxsackie
Mexico	1978	Complete	11/11	Coxsackie, Rota
Israel	1978	Disinfection	12/18	Polio, Echo
India	1978	Disinfection	19/74	NR
Romania	1972-77	Complete	8/220	Polio, Coxsackie
Virginia	1975	Complete	4/12	Polio
Florida	1975	Disinfection	1/10	Echo

a = Sedimentation, filtration and disinfection; b = Not reported.

Table IV. Water Quality Parameters Associated with a Michigan Water Treatment Plant that Applied Chlorine Just Prior to Sand Filtration[25]

	Source Water		Finished Water			
Date	Viruses[a]	Coliforms[b]	Chlorine[c]	Viruses[d]	Coliforms[b]	THM[e]
5/81	3	1,574	3.8	<1	<1	189
6/81	14	11,210	3.0	<1	<1	221
7/81	23	48,080	3.1	<1	<1	242
8/81	3	8,303	4.8	<1	<1	277
9/81	90	12,439	3.0	<1	<1	262
10/81	54	6,810	3.9	<1	<1	187
11/81	13	2,908	5.0	<1	<1	176
12/81	64	1,974	2.6	<1	<1	124
1/82	48	1,346	4.6	<1	<1	107
2/82	293	7,540	3.1	<1	<1	114
3/82	71	1,760	2.6	<1	<1	113
4/82	5	3,818	2.8	<1	<1	131
5/82	0	2,155	2.5	<1	<1	149

a = Monthly PFU averages/380 liters (100 gal); b = Monthly geometric mean CFU/100 ml; c = Monthly mg/L averages (total residuals); d = PFU/1,900 liters; e = µg/liter.

Table V. Dose Response of Human Subjects to Oral Exposure of Relatively Low Levels of Enteric Microorganisms[32,33]

Organism	Dose	No. Pos./No. Dosed (%)
Shigella flexneri	180	9/36 (22)
Shigella dysenteriae	10	1/10 (10)
Giardia lamblia	10	2/2 (100)
Poliovirus 1	50	3/6 (50)
Echovirus 12	330	15/50 (30)